Description of Mixed-Phase Clouds in Weather Forecast and Climate Models

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LONG-TERM GOALS

To develop an improved parameterization of so-called mixed-phase stratocumulus in numerical models of weather and climate, and of their impact on the surface energy budget over the Arctic Ocean, their impact on the vertical structure of the lower troposphere and relationships to larger scale meteorology.

OBJECTIVES

Develop a process-level understanding on why so-called mixed-phase stratocumulus are so common, by far the most common type of clouds in the Arctic, when basic thermodynamics seems to suggest that ice and liquid particles cannot coexist for long times. Find linkages between dynamic processes on all scales, ranging from long range transport to turbulent motions, and cloud micro-physics.

APPROACH

Developing new parameterizations is a multi-scale and multi-tool endeavor that links investigations of field observations to analysis of meteorology, process-level modeling and full-scale numerical modeling.

This project takes its cue from field experiments, mostly from the *Arctic Summer Cloud Ocean Study* (ASCOS), which was a summer expedition on the Swedish icebreaker Oden during the summer of 2008 as part of the International Polar Year, and a new expedition scheduled for the summer of 2014, also on the icebreaker Oden: the *Arctic Cloud in Summer* (or ACSE) experiment, which is a part of a larger effort focusing on greenhouse gas exchange in the Arctic; the SWERUS-C3 expedition. On both of this we rely on a combination of surface based in-situ observations, of for example the surface energy balance and profiles from radiosoundings, and a suite of advanced surface based remote sensing instrumentation, using Doppler radar, lidar and micro-wave radiometry. The remote sensing instruments allows for estimations of details of the clouds such as dynamics, bulk properties as well as cloud micro-physics at high resolution in time and the vertical.

Understanding gained from field experiments will be generalized using process modeling (Large Eddy Simulation & Cloud Resolved Modeling) and the resulting parameterizations will be tested in the US Navy COAMPS regional model before being migrated to GCM models (e.g. OpenIFS and/or EC-Earth or NAVGEMS).

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This is a highly collaborative project that rests on expertise and collaborations gained over the last decade or more. Key staff at Stockholm University beside the PIs (Profs. Michael Tjernström& Gunilla Svensson) involve two PhD students (Georgia Sotiropolo, hired on this grant for ACSE, and Cecilia Wesslen, working on the ASCOS data), two post-doc (Dr Julien Savre for LES/CRM modeling and one for ACSE, yet to be hired), and Dr Annica Ekman who is working with the LES/CRM modeling and is an expert on aerosol/cloud interaction. For logistics during ACSE we interact with Profs. Martin Jakobsson and Örjan Gustavsson, Stockholm University, as Lead PIs for SWERUS-C3.

Dr Joseph Sedlar at the Swedish Meteorological and Hydrological Institute will be co-advising the new PhD stundet; Dr Sedlar got his degree on work from the ASCOS data and is a key asset for his knowledge in remote sensing, both from the surface and from satellite.

For the ACSE field phase, we rely on Drs Matthew Shupe and Ola Persson at NOAA/ESRL in Boulder, Colorado, for the remote sensing instrumentation, and on Dr Ian Brooks and his group from Leeds University in Leeds, UK, for surface energy observations and some of the remote sensing equipment.

WORK COMPLETED

The first thing that has to happen with a program of this kind is to find the funding for the field program. This is an ongoing work until the icebreaker leaves the harbor; this grant is a very important part of this, but the work of securing funding for SWERUS-C3 started even earlier, in spring 2011, and a major consortia grant was secured early 2012 when the *Knut and Alice Wallenberg Foundation* granted 43MSEK for ship time and part of the staff and equipment requirements for the whole SWERUS-C3 expedition.

The next thing that needs to happen is hiring of staff. This is also an ongoing task; the PhD student recruited under this particular contract starts 1 October but the hiring of academic staff at a Swedish university is a protracted process. While this was started in April with a faculty-wide announcement for new PhD-positions and a decision was taken already in late June, GS could not relocate to Sweden and start her position until now. Next in line is the hiring of a post-doc also for ACSE; in Sweden a post-doc is maximized to two years, and to make any sense for the field phase cannot be hired to early for a 2014 deployment.

After this, proposals were submitted to the Swedish Research Council's board for Infrastructure for additional ship time and for instruments and installations on board; these are now pending and a decision will be taken by early November, in time for the start of the Swedish fiscal year on 1 January. Work is also ongoing in ACSE for proposals to NSF/OPP in the US and to NERC in the UK to cover some of the costs for the ACSE field phase.

Some science work has been completed following the successful ASCOS campaign is of large interest for this project although not funded by this grant. A survey of summer Arctic meteorology from several expeditions was published early this year (Tjernström et al. 2012) as was a study using data from ASCOS, SHEBA and from Barrow compiled to relate the vertical thermodynamic structure to the clouds (Sedlar et al. 2012). Preliminary work on the boundary-layer structure and how it relates to clouds will be summarized in a paper later this year (Brooks et al. 2012, manuscript in progress). One novel feature of this work is the creation of a time-height cross-section of "observed" *Richardson number*, based on observations, from temperature soundings by a scanning microwave radiometer,

complemented by cloud phase information from the cloud radar, and wind information from a combination of Doppler sodar and wind profiler data. To our knowledge, this has never been accomplished before from observations. A study of the performance of the *Arctic System Reanalysis* (ASR) using data from ASCOS has been concluded and will be published this year. Finally several studies of the performance of the CMIP5 models in the Arctic are near compleation; one paper on EC-Earth was published (Koenik et al. 2012).

RESULTS

Results that have been published so far are entirely based on outcomes from the ASCOS field project and are part of this effort but are not funded by this grant. A summary of all these results can be found in a joint special issue across Atmospheric Chemistry and Physics, Ocean Sciences and Atmospheric Measurement Techniques.

An overview of the meteorological conditions during ASCOS with a detailed analysis of the ice drift was published in Tjernström et al. (2012). In this work, data from similar summer periods from several expeditions was compiled for the first time. In another study, data from ASCOS, SHEBA and from Barrow was compiled to relate the vertical thermodynamic structure to the clouds (Sedlar et al. 2012). In this study in particular the fact that the cloud top – in contrast to elsewhere in the world – protrudes into the capping inversion was investigated. This was also the subject of a satellite climatology study, showing the same feature (Devasthale et al. 2012). The importance of mixed-phase stratocumulus and their sensitivity to microphysics assumptions were demonstrated in a modeling study using the UK Unified Model (Birch et al. 2012).

Preliminary work on the retrieval of turbulence information inside clouds from the Doppler radar was compared to in-situ turbulence observations from an instrument deployed by tethered sounding was also published (Shupe et al. 2012). The results shows that the Doppler radar turbulence estimates can be used reliably as long as there is an inertial sub-range present in power spectra of the vertical Doppler velocity. One clear feature from the boundary-layer structure and the Ri-number data that we are now trying to understand is the connection, or lack thereof, between turbulent generated by surface friction and by buoyancy from cloud top cooling. When insufficient, lack of coupling results in the formation of a secondary inversion between the surface and the cloud base, below the cloud-top capping inversion. This in term implies that the cloud layer is cut off from surface fluxes of moisture and aerosols; yet the cloud persists for days on end.

The evaluation of the ASR using ASCOS data is also completed and a manuscript is forthcoming before the end of the year. In brief summary, the ERA-Interim, which is the global product that is forcing the regional ASR, generally performs better in describing some of the even-like features that were found from ASCOS, but has significant systematic errors, while different versions of the ASR, with higher spatial resolution and more advanced model physics, has smaller systematic errors but fail in some important event-like features, interestingly enough one being the describing a week-long episode with so-called mixed-phase stratocumulus from the observations and their effects on the surface energy balance (Tjernström et al. 2012; Sedlar et al. 2011). None of the ASR versions form mixed-phase clouds during this period, instead they have clear conditions and much to low surface temperatures (Wesslen et al. 2012, personal communication). Finally, although the manuscript is not finished yet, a summary statement on the performance of the CMIP5 models in the Arctic could be that some of the models show improvements compared to CMIP3, but as an ensemble there is no major improvement, at least as far clouds go.

IMPACT/APPLICATIONS

Better treatment of clouds in model of the Arctic is the number one important tissue for understanding the surface energy balance and thus the melting and freezing of sea ice, now and into the future.

RELATED PROJECTS

This project is a follow-up of important parts of ASCOS (www.ascos.se) and a part of the SWERUS-C3 field program (http://swerus-c3.geo.su.se/). A future program of which ASCE may be seen as a pilot project is the MOSAiC program. On the modeling side, ASCE is related to the Arctic System Reanalysis (http://polarmet.osu.edu/ASR/), the EC-Earth program (http://ecearth.knmi.nl/) and the EUCLIPSE EU-project (http://www.euclipse.eu/index.html).

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